Odontology (2011) 99:148–154
DOI 10.1007/s10266-011-0011-8

ORIGINAL ARTICLE

FEM analysis of the mandibular first premolar with different post diameters

Je-Kang Du · Wei-Ko Lin · Chau-Hsiang Wang · Huey-Er Lee · Hung-Yuan Li · Ju-Hui Wu

Received: 29 June 2010 / Accepted: 31 October 2010 / Published online: 14 April 2011

Abstract Several reports have pointed out that endodontically treated teeth can lack strength, and that the teeth can be reinforced using posts. However, it has not been clear how to select posts that meet the needs of most clinical situations, particularly in terms of the post diameter, which has a major influence on the occurrence of root fracture. The purpose of this study was to analyze the stress distributions of posts of various diameters during masticatory loads using a finite element method. A 3-dimensional (3D) finite element model of a lower first premolar was developed. We used the image software Geomagic Studio (3D Digital 2002; Geomagic, Research Triangle Park, NC, USA) to reduce the post diameter by 6 ratios to a root diameter of 20, 30, 40, 50, 60, and 80% and then individually implemented them into the root of a tooth. A chewing static force of 100 N was applied as a 45° diagonal load on the buccal cusp tip, and the $\sigma_{\text{von Mises}}$ and $\sigma_{\max}$ stresses were calculated. Analysis of the $\sigma_{\text{von Mises}}$ values revealed that the stresses were concentrated in the middle 1/3 of both the post and the root surface for all models, as were the $\sigma_{\max}$ values. The results also indicated that when the diameter of the post was 50% of that of the root, the stress distributions of the post and the root surface were most favorable. In conclusion, the clinical implications of the results will need to be further studied and discussed.

Keywords Post · Endodontically treated tooth · Finite element method · Stress analysis

Introduction

A post supports the core and crown, but can also compete for space with root dentin in the tooth. In making prostheses, dentists must decide how much root dentin to retain during placement of the post to avoid the risk of root fracture. At times, it is necessary to remove infected dentin during a root canal or to increase the likelihood of retention of posts by enlarging the space within the root canal [1]. However, previous studies have demonstrated that overpreparation of canals can weaken the root structure of endodontically treated teeth [2–5], increasing the failure rate of the prostheses. In reviewing the literature [6], there are three distinct philosophies concerning the preparation of post diameters for endodontically treated teeth. The conservationist group advocates limited instrumentation of the canal after removal of the gutta-percha. Use of the narrowest possible diameter allows fabrication of a post to the desired length. The proportionist group believes the post space should be a given fraction of the root width, usually having an apical diameter less than 1/3 of the narrowest dimension of the root diameter at the terminus of the post space. The preservationist group suggests that a minimal amount of tooth structure should remain, usually between 1.0 and 1.75 mm of sound dentin surrounding the entire surface of the post. All three philosophies point out that the remaining root dentin plays an important role in implementation of posts. However, there is little scientific

J.-K. Du · C.-H. Wang · H.-E. Lee · J.-H. Wu (✉)
Department of Dentistry, Kaohsiung Medical University Hospital, No.100, Tz-you 1st Rd., Kaohsiung 807, Taiwan
e-mail: wu.juhui@msa.hinet.net

W.-K. Lin · C.-H. Wang · H.-E. Lee
Faculty of Dentistry, College of Dental Medicine, Kaohsiung Medical University, Kaohsiung, Taiwan

H.-Y. Li
Department of Mold and Die Engineering, National Kaohsiung University of Applied Science, Kaohsiung, Taiwan

evidence to support these philosophies. Thus, an analysis of the mechanical forces associated with post diameter implementation in the root is important for clinical dentists.

The direct measurement of tooth strain using electrical strain gauges in vivo is impractical. Photoelastic measurements have been made using physical models of the teeth, but these are of limited quantitative value. It is also difficult to reduce the diameter of the post according to a ratio and the form of the root diameter using the photoelastic technique. The most common approach to analyzing biomechanical problems in humans indirectly has been use of the finite element method (FEM). With 3-dimensional mathematical models, it is much easier to model structures with intricate shapes and to quantify complex mechanical behavior at any theoretical point.

This study used a 3-dimensional finite element model (3D FEM) to analyze the stress distributions of the lower first premolar after insertion of posts with various diameters.

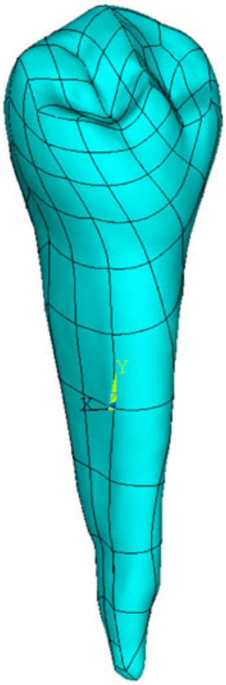

Fig. 1 Solid model of a lower 1st premolar

Methods

The finite element analysis was conducted using a lower first premolar extracted by forceps from a patient who received orthodontic treatment. The coronal height was 9 mm, the root length was 14.5 mm, the mesiodistal dimension of the cementoenamel junction (CEJ) was 5 mm, and the buccolingual dimension of the CEJ was 6.5 mm. There was no abnormality in anatomical appearance. Using a 3D digitizer (3D scanner optoTOP, Breuckmann, Meersburg, Germany), we developed a model of the lower first premolar using the top-down method (a method for establishing solid models by volumes → areas → lines → keypoint sequence). The procedure for building the model was as follows:

1. Obtain the geometry of the lower first premolar from an initial scan (Fig. 1).
2. Prepare the tooth according to the metal crown modification standard, followed by a second scan.
3. Use the image software Geomagic Studio (3D Digital 2002) to reduce the diameter of the post by 6 ratios to a root diameter of 20, 30, 40, 50, 60, and 80%, then individually implement them into the root of the tooth.
4. After combining the images of the above three procedures using Boolean expressions, develop six different models (A–F) of the lower first premolar based on the six different diameters of the posts (Fig. 2).

The retrieval and synthesis of the above images were performed using Geomagic Studio software (3D Digital 2002). During scanning, we used a splint with markings to stabilize the tooth and aid in image combination (Fig. 3). Six models were obtained as described above, simulating the structure of the alveolar bone with ANSYS (Swanson Analysis Systems, Houston, PA, USA) for the analyses. Using Free Mesh, these 3D models were developed into finite element models of the lower first premolar (Fig. 4); quantities for the nodes and elements upon completion are given in Table 1. In brief, we used gutta-percha within the apical 4 mm of the root of the post space, gold alloy for the crown, and palladium alloy for the post and core. The material properties are shown in Table 2 [7].

To simulate the origin site of the mylohyoid and masseter muscles, the models were constrained at the buccal and lingual surfaces of the alveolar bone boundaries, and the freedom was 0. A force of 100 N was applied diagonally at 45° to the buccal cusp tip (Fig. 5).

In this experiment, we assumed that all of the materials were isotropic, linearly elastic, and homogeneous, and that all of the elements (solid45; 8 nodes having 3 degrees of freedom at each node) were tightly bonded. Using ANSYS, the post-processing function created a stress distribution diagram. We then analyzed the stress distributions and stress concentrations of the post and remaining dentin of the root for each modeled diameter of the post.

Results

The stress distributions for the post and the remaining dentin were represented by the von Mises stress, $\sigma_{\text{von Mises}}$, and the tensile stress, $\sigma_{\max}$. On applying the 45° diagonal

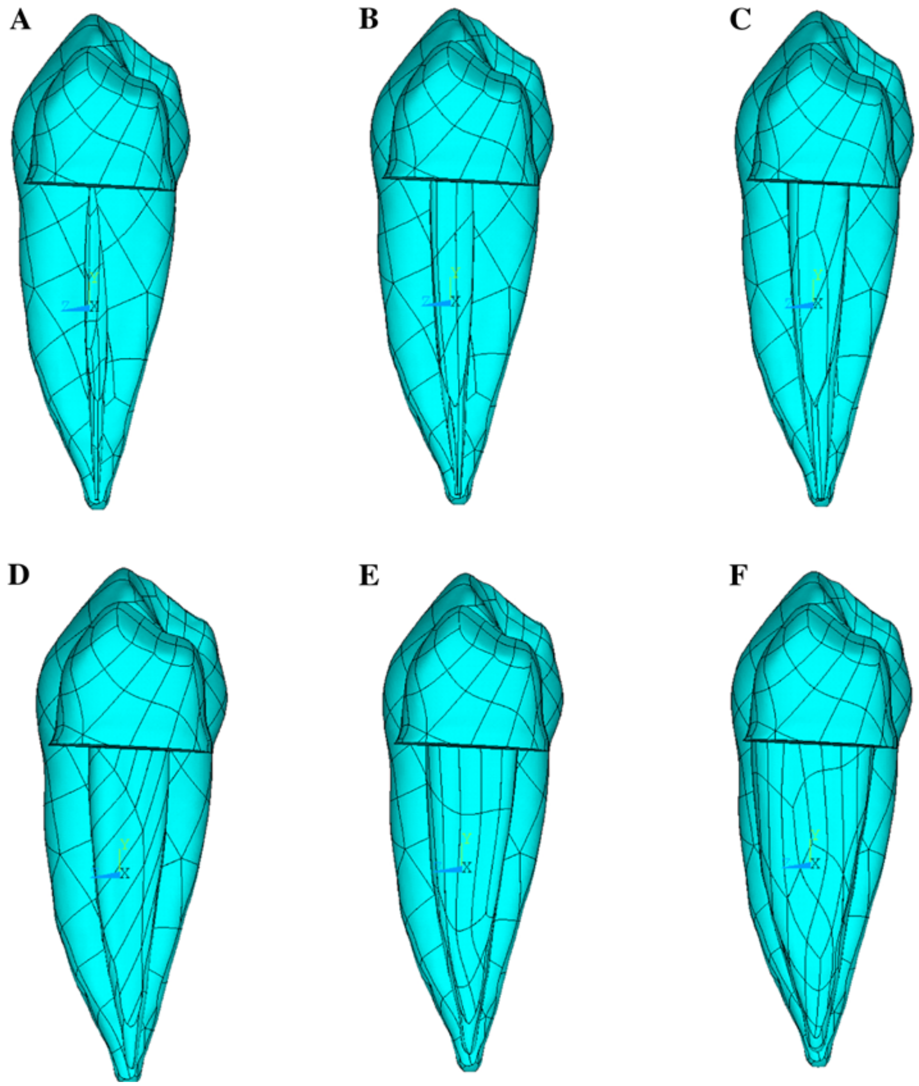

Fig. 2 Solid model of 6 ratios of post to root diameter: (A) 20%, (B) 30%, (C) 40%, (D) 50%, (E) 60%, and (F) 80%

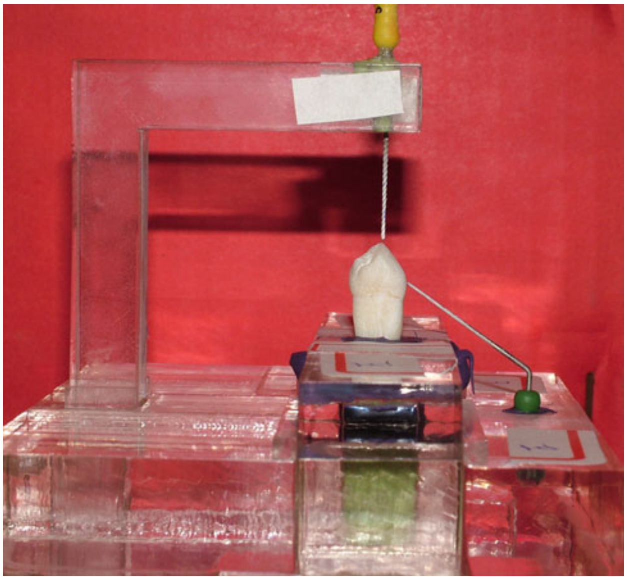

Fig. 3 Splint with markings to stabilize the image combination

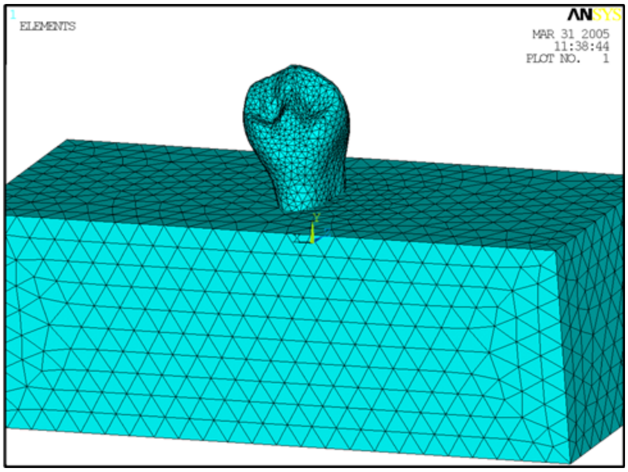

Fig. 4 Finite element model of the lower 1st premolar with a bone block

Table 1 Numbers of elements and nodes of the 6 different models of post to root diameters: (A) 20%, (B) 30%, (C) 40%, (D) 50%, (E) 60%, and (F) 80%

	A	B	C	D	E	F
Elements	62,412	60,242	58,818	60,915	59,029	59,057
Nodes	11,682	11,307	11,065	11,389	11,118	11,114

Table 2 Mechanical properties of the components of the model

	Young's modulus (MPa)	Poisson's ratio
Dentin	18,600	0.31
Palladium alloy	99,000	0.30
Gold alloy	77,000	0.33
Alveolar bone	1,260	0.30
Gutta-percha	0.69	0.45

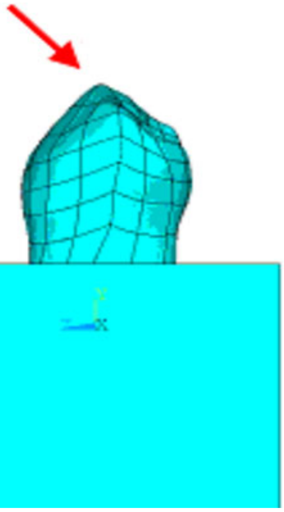

Fig. 5 A load of 100 N applied at 45° to the buccal cusp tip

force, the $\sigma_{\text{von Mises}}$ stresses were concentrated on the buccal and lingual sides of the middle 1/3 of the root for both the post and the root dentin. The peak von Mises stress was on the lingual side. The $\sigma_{\max}$ stresses were concentrated on the buccal side of the middle 1/3 of the root for both the post and root dentin. The peak tensile stress was on the buccal side (Figs. 6, 7). The peak $\sigma_{\text{von Mises}}$ and $\sigma_{\max}$ stresses are shown in Table 3 for the post and root dentin.

When the diameter of the post was 50% of that of the root (model D), the peak $\sigma_{\text{von Mises}}$ and $\sigma_{\max}$ stresses were both at a minimum in the root dentin among the 6 models. The peak $\sigma_{\text{von Mises}}$ for the post was at a minimum when the diameter of the post was 50% of that of the root, and the peak $\sigma_{\max}$ for the post was at a minimum when the diameter of the post was 20% of that of the root (model A). There were no significant tendencies in the maximum stress values with different post diameters.

Discussion

In previous studies [4] conducting stress analyses of various post diameters, a limited number of different ratios of post diameter to the root were considered. However, dentists often face such problems clinically. The stress on the root depends on the nature of the post, which in turn depends on the diameter of the canal after endodontic treatment. The type of post directly affects the distribution of occlusal stresses. However, many non-artificial factors (e.g., the innate condition of the canal, the infected area of the dentin, etc.) contribute to difficulty in predicting the appropriate post diameter or the amount of remaining dentin. Therefore, it is of utmost importance for clinicians to understand the effects of different post diameters on stress distributions. To avoid inaccuracies seen in 2D model results, we used a 3D model to more closely simulate the actual situation. In addition, we used CAD-CAM technology to simulate posts with various ratios of the diameter to the root diameter for the stress analysis. Based on these results, we concluded that stress concentration was the lowest in both the root dentin and the post when the diameter of the post was 50% of that of the root.

It is difficult to analyze stress distributions in the teeth, especially the roots, after the insertion of posts in vivo. FEM provides an indirect approach for analyzing complex problems related to teeth and the surrounding structures, but there are some limitations. The materials used in this study were assumed to be linearly elastic, homogeneous, and isotropic. There was no cement layer or periodontal ligament built into the model, and we used a simple bone block. The cement layer between the post and the dentin was too thin to adequately model in the finite element simulation; therefore, the cement was treated as part of the dentin because the mechanical properties of dentin and cement are similar [8]. The periodontal ligament is a viscoelastic material that displays a combination of elastic and viscous properties [9]. Some studies have included a periodontal ligament layer in the FEM; however, it was treated as an elastic material [8, 10, 11]. In this study, we focused on the stress distribution within the root dentin and the post itself, and the impact of the periodontal ligament on the stress distribution was considered to be negligible due to its thinness [12].

There are differing views on the effect of the ratio of the post diameter to the root diameter [6, 13–17]. Many investigators support the post diameter being less than 1/3 that of the root. The results of this study, based on the mechanical stress analysis, do not support this point of

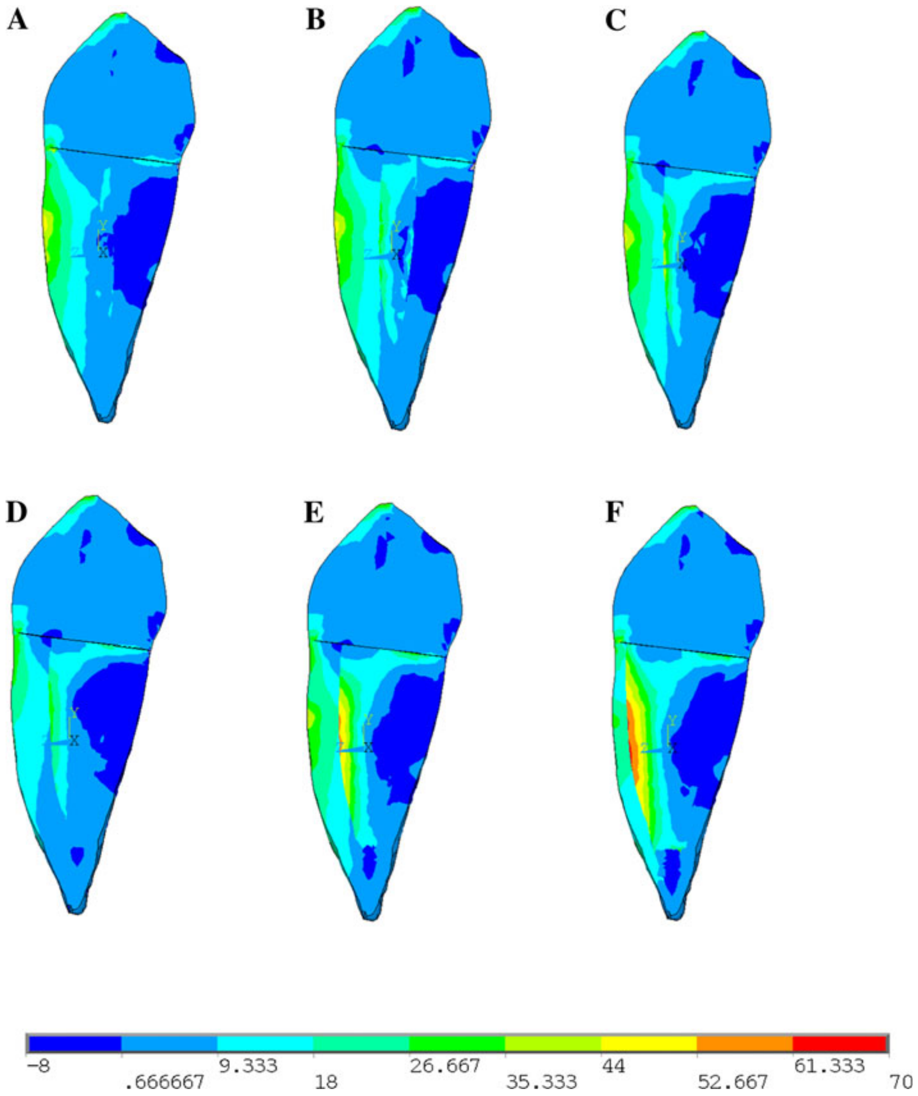

Fig. 6 Distribution of $\sigma_{\max}$ values (Mpa) within the lower 1st premolar with various post to root diameters: (A) 20%, (B) 30%, (C) 40%, (D) 50%, (E) 60%, and (F) 80%

view. Previous studies conducting stress analysis of posts have nearly all been based on a single-rooted tooth. The results for the buccal–lingual section of the tooth suggest that the best ratio derives from the post of the canal and the dentin on both the buccal and lingual sides sharing 1/3 of the force. However, it is difficult to obtain evidence to prove this. Using a computer simulation, the present study overcame difficulties associated with the implementation of the post into the root, such as an inaccurate ratio of the post diameter to the root diameter or achieving the expected post diameter. More importantly, there was no need to change any other parameters apart from the relationship of the post diameter to the root dentin. Thus, this may be the only method that can analyze the stresses associated with different post diameters in a single tooth.

The present study indicated that the stress concentration was lowest in both the root dentin and the post when the post diameter was 50% of that of the root. These results appear to support the approach recommended by the proportionists; however, the dentin strength should be taken into consideration [18, 19]. Over-enlargement of the root canal weakens the root dentin and increases the risk of root fracture. We concluded that the stress was lowest when the post diameter was 50% of that of the root, but we do not know whether this level of stress may cause root fracture.

Sorensen [20] suggested that the presence of posts in anterior teeth does not have a great influence on root fracture; however, most studies on posts have focused on central incisors [8, 10–12]. The present study used the lower first premolar to investigate strengthening with a post in posterior teeth for which less is known. We also used a single-root posterior tooth model as a foundation for further investigation of the effects of post diameter on stress in multi-rooted posterior teeth.

The results demonstrated that there was a difference in the stress distributions with differing post diameters. When

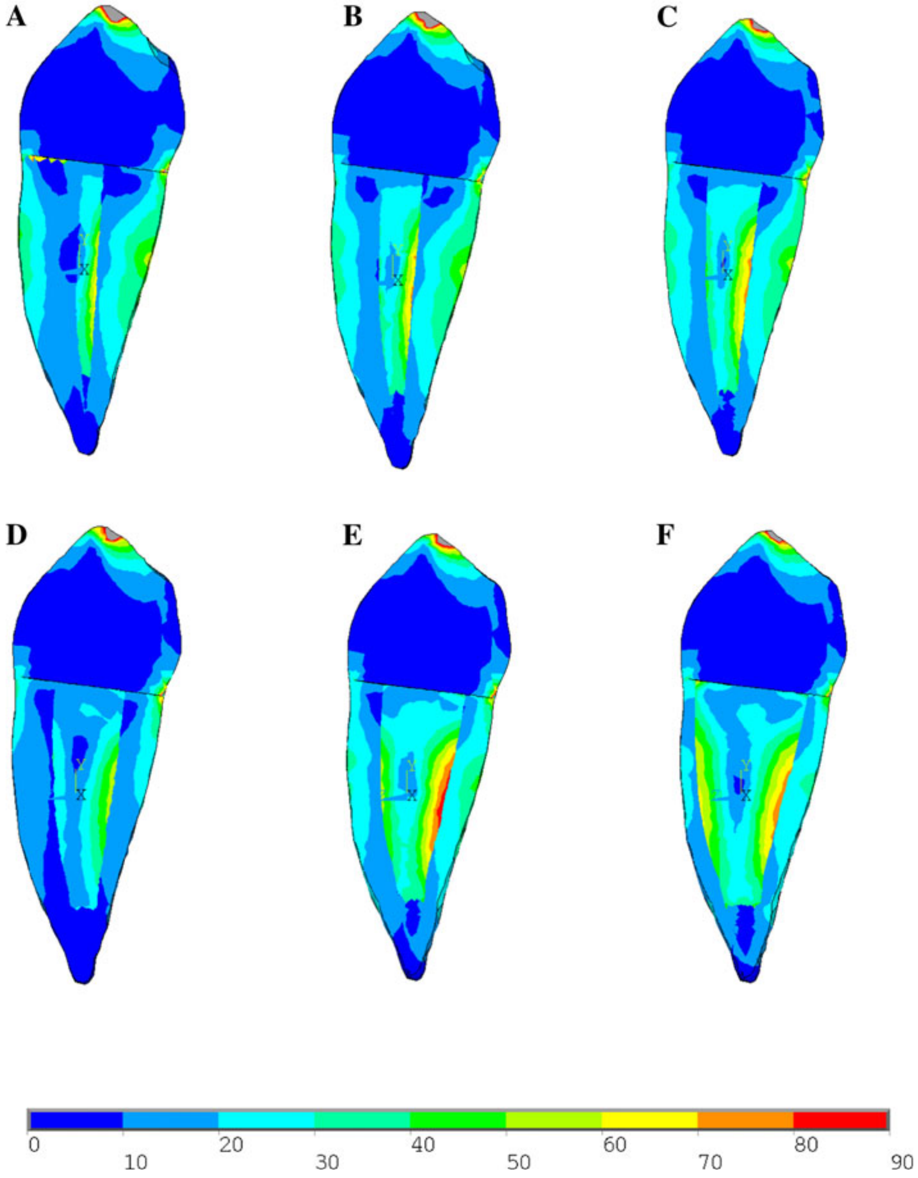

Fig. 7 Distribution of $\sigma_{\text{von Mises}}$ values (Mpa) within the lower 1st premolar with various post to root diameters: (A) 20%, (B) 30%, (C) 40%, (D) 50%, (E) 60%, and (F) 80%

Table 3 Peak (Mpa) $\sigma_{\text{von Mises}}$ and $\sigma_{\max}$ stresses within the post and root of 6 different models with various post to root diameters: (A) 20%, (B) 30%, (C) 40%, (D) 50%, (E) 60%, and (F) 80%

	A	B	C	D	E	F
$\sigma_{\text{von Mises}}$ of the post	80.8	96.1	90.2	57.4	96.1	88.1
$\sigma_{\text{von Mises}}$ of the root	62.2	60.9	59.5	22.1	50.3	43.0
$\sigma_{\max}$ of the post	17.3	41.8	54.6	37.4	61.3	73.5
$\sigma_{\max}$ of the root	57.8	57.0	55.8	22.9	49.9	33.5

the post diameter increased from 20 to 50% of the root diameter, there was a smaller peak stress on the dentin. The 80% post model indicated less stress to the root than the 60% post model; it is possible that the increased diameter of the post shares the force to the root along with the rest of the tooth. Although the maximum stress on the root dentin was smaller than in the 60% model, the 80% model had thinner root dentin, implying that the 80% model does not necessarily indicate a lower chance of root fracture. In addition, the material of the post may affect the stress distribution. Further study is needed to replicate these results and verify whether they can be applied to different post materials.

This study analyzed 6 different post diameters in the lower first premolar. The results indicated that when the diameter of the post was 50% of that of the root, the stress distributions of the post and dentin were most favorable. We support preserving as much of the dentin as possible, with the caveat that the post diameter must be broad enough to resist occlusal forces. At times, dentists must enlarge the diameter of a root canal for mechanical or pathological reasons, and in these cases, we suggest that

Table 4 Clinical recommendations for preparation of single-rooted teeth

Tooth	1/2 of the root	1/3 of the root
Maxillary teeth		
Central incisor	170[a] (6)[b]	110[a] (3)[b]
Lateral	140 (4)	90 (2)
Canine	150 (5)	100 (2)
Second premolar	130 (4)	90 (2)
Mandibular teeth		
Central incisor	100 (2)	70 (1)
Lateral	100 (2)	70 (1)
Canine	150 (5)	100 (2)
First premolar	130 (4)	90 (2)
Second premolar	140 (4)	90 (2)

[a] Size of ISO

[b] Size of the pesso reamer

the diameter be limited to less than 50% of the root diameter. For convenience in clinical treatment, we compare root diameters 4 mm from the apex as measured by Tilk [21] and list recommended post diameters along with ISO and Pesso reamer sizes (Table 4).

Conclusions

Based on the results and limitations of this study, the following conclusions were made:

1. When the diameter of the post was 50% of that of the root, the stress distributions of the post and dentin were most favorable.
2. In clinical practice, it is recommended to preserve as much of the dentin as possible. Excessive post diameter should be avoided.

References

1. Standlee JP, Caputo AA, Hanson EC. Retention of endodontic dowels: effects of cement, dowel length, diameter, and design. J Prosthet Dent. 1978;39:400–5.
2. Trope M, Maltz DO, Tronstad L. Resistance to fracture of restored endodontically treated teeth. Endod Dent Traumatol. 1985;1:108–11.
3. Sapone J, Lorencki SF. An endodontic-prosthodontic approach to internal tooth reinforcement. J Prosthet Dent. 1981;45:164–74.
4. Grieznis L, Apse P, Soboleva U. The effect of 2 different diameter cast posts on tooth root fracture resistance in vitro. Stomatologija. 2006;8:30–2.
5. Reeh ES, Messer HH, Douglas WH. Reduction in tooth stiffness as a result of endodontic and restorative procedures. J Endod. 1989;15:512–6.
6. Lloyd PM, Palik JF. The philosophies of dowel diameter preparation: a literature review. J Prosthet Dent. 1993;69:32–6.
7. Reinhardt RA, Krejci RF, Pao YC, Stannard JG. Dentin stresses in post-reconstructed teeth with diminishing bone support. J Dent Res. 1983;62:1002–8.
8. Ko CC, Chu CS, Chung KH, Lee MC. Effects of posts on dentin stress distribution in pulpless teeth. J Prosthet Dent. 1992;68:421–7.
9. Picton DC, Wills DJ. Viscoelastic properties of the periodontal ligament and mucous membrane. J Prosthet Dent. 1978;40:263–72.
10. Ho MH, Lee SY, Chen HH, Lee MC. Three-dimensional finite element analysis of the effects of posts on stress distribution in dentin. J Prosthet Dent. 1994;72:367–72.
11. Pao YC, Reinhardt RA, Krejci RF. Root stresses with tapered-end post design in periodontally compromised teeth. J Prosthet Dent. 1987;57:281–6.
12. Rubin C, Krishnamurthy N, Capilouto E, Yi H. Stress analysis of the human tooth using a three-dimensional finite element model. J Dent Res. 1983;62:82–6.
13. Fernandes AS, Dessai GS. Factors affecting the fracture resistance of post-core reconstructed teeth: a review. Int J Prosthodont. 2001;14:355–63.
14. Fernandes AS, Shetty S, Coutinho I. Factors determining post selection: a literature review. J Prosthet Dent. 2003;90:556–62.
15. Perel ML, Muroff FI. Clinical criteria for posts and cores. J Prosthet Dent. 1972;28:405–11.
16. Stern N, Hirshfeld Z. Principles of preparing endodontically treated teeth for dowel and core restorations. J Prosthet Dent. 1973;30:162–5.
17. Sokol DJ. Effective use of current core and post concepts. J Prosthet Dent. 1984;52:231–4.
18. Lehman ML. Tensile strength of human dentin. J Dent Res. 1967;46:197–201.
19. Renson CE, Braden M. Experimental determination of the rigidity modulus, Poisson's ratio and elastic limit in shear of human dentine. Arch Oral Biol. 1975;20:43–7.
20. Sorensen JA, Martinoff JT. Intracoronal reinforcement and coronal coverage: a study of endodontically treated teeth. J Prosthet Dent. 1984;51:780–4.
21. Tilk MA, Lommel TJ, Gerstein H. A study of mandibular and maxillary root widths to determine dowel size. J Endod. 1979;5:79–82.